PRODUCING AUTOMATIC "PAINTING" EFFECTS IN IMAGES

Field of the Invention

The present invention relates to an image processing method and apparatus and, in particular, discloses a Producing Automatic "Painting" Effects in Images.

The present invention further relates to the field of image processing and in particular to producing artistic effects in images.

Background of the Invention

Recently, it has become quite popular to provide filters which produce effects on images similar to popular artistic painting styles. These filters are designed to take an image and produce a resultant secondary image which appears to be an artistic rendition of the primary image in one of the artistic styles.

One extremely popular artist in modern times was Vincent van Gogh. It is a characteristic of art works produced by this artist that the direction of brush strokes in flat areas of his paintings strongly follow the direction of edges of dominant features in the painting. For example, his works entitled "Road with Cypress and Star", "Starry Night" and "Portrait of Doctor Gachet" are illustrative examples of this process.

It would be desirable to provide a computer algorithm which can automatically produce a "van Gogh" effect on an arbitrary input image.

Summary of the Invention

It is an object of the present invention to produce automatic "van Gogh" type effects in images.

In accordance with the first aspect of the present invention there is provided a method of automatically processing an image comprising locating within the image features having a high spatial variance and stroking the image with a series of brush strokes emanating from those areas having high spatial variance.

Preferably, the brush strokes have decreasing sizes near important features of the image.

Additionally, the position of a predetermined portion of

brush strokes can undergo random jittering.

Brief Description of the Drawings

Notwithstanding any other forms which may fall within the scope of the present invention, preferred forms of the invention will now be described, by way of example only, with reference to the accompanying drawings which:

Fig. 1 illustrates the major steps in the preferred embodiment;

Fig. 2 illustrates the Sobel filter co-efficients utilised within the preferred embodiment;

Figs. 3 & 4 illustrate the process of offsetting curves utilised in the preferred embodiments;

Description of the Preferred and Other Embodiments

The preferred embodiment is preferable implemented through suitable programming of a hand held camera device such as that described in Australian Provisional Patent Application entitled "Image Processing Method and Apparatus (ART01)" filed concurrently herewith by the present applicant the content of which is hereby specifically incorporated by cross reference.

The aforementioned patent specification discloses a camera system, hereinafter known as an "Artcam" type camera, wherein sensed images can be directly printed out by an Artcam portable camera unit. Further, the aforementioned specification discloses means and methods for performing various manipulations on images captured by the camera sensing device leading to the production of various effects in any output image. The manipulations are disclosed to be highly flexible in nature and can be implemented through the insertion into the Artcam of cards having encoded thereon various instructions for the manipulation of images, the cards hereinafter being known as Artcards. The Artcam further has significant onboard processing power by an Artcam Central Processor unit (ACP) which is interconnected to a memory device for the storage of important data and images.

In the preferred embodiment there is described an algorithm which will automatically convert a photographic image into a "painted" rendition of that image which replaces groups

of pixels in the input image with "brush strokes" in the output image. The algorithm works by automatically detecting dominant edges and propagating the edge direction information into flat areas of the image so that brush strokes can be oriented in such a way as to approximate the van Gogh style. The algorithm is suitable for implementation on the aforementioned Artcam device.

Turning initially to Fig. 1, the algorithm comprises a number of steps 1. These steps include an initial step of filtering the image to detect its edges 2. Next, the edges are thresholded or "skeletonised" 4 before being processed 5 to determine the final edges 6. Bézier curves are then fitted to the edges. Next, the curves are offset 7 and brush strokes are placed on final image 8. The process 7 and 8 is iterated until such time as the image is substantially covered by brush strokes. Subsequently, final "touching up" 9 of the image is performed.

Turning now to describe each step in more detail. In the first step 2 of filtering to detect edges, a Sobel 3 x 3 filter having co-efficient sets 12 and 13 as illustrated in Fig. 2 can be applied to the image. The Sobel filter is a well known filter utilised in digital image processing and its properties are fully discussed in the standard text "Digital Image Processing" by Gonzalez and Woods published 1992 by the Addison - Wesley publishing company of Reading, Massachusetts at pages 197-201. The Sobel derivative filter can be applied by either converting the image to greyscale before filtering or filtering each of the colour channels of an image separately and taking the maximum. The result of Sobel filtering is the production of a greyscale image indicating the per-pixel edge strength of the image.

Next, the resultant per-pixel edge strength image is thresholded 3 so as to produce a corresponding thresholded binary image. The threshold value can be varied however, a value of 50% of the maximum intensity value is suitable. For each pixel in the edge strength image the pixel is compared with the threshold and if it is greater than the threshold a

"one" is output and if it is less than the threshold a "zero" is output. The result of this process is to produce a threshold edge map.

Next, the thresholded edge map is "skeletonised" at step 4 of Fig. 1. The process for skeletonising an image is fully set out in the aforementioned reference text at pages 491-494 and in other standard texts. The process of skeletonisation produces a "thinned" skeletonised edge map maintaining a substantial number of characteristics of the thresholded edge map.

In a next step the edges of the skeletonised edge map are determined to yield a data structure which comprises a list of further lists of points within the image. Preferably, only edges having a length greater than a predetermined minimum are retained in the list.

As the skeletonised image contains only single-pixel-width edges, possibly with multiple branches, the following algorithm expressed as a C++ code fragment sets out one method of determining or identifying the points which belong to each contiguous edge in the skeletonised image. It breaks branching edges into separate edges, and chooses to continue along the edge in the direction which minimises the curvature of each branch - ie. at a branch-point it favours following the branch which induces the least curvature. The code is as follows:

```
void
FollowEdges
(
    Image& image,
    int minimumEdgeLength,
    PointListList& pointListList
)
(
    pointListList.Erase();
    for (int row = 0; row < image.Height(); row++)
    {
        for (int col = 0; col < image.Width(); col++)
        {
```

```
                If (image[row][col] > 0)
                {
                        PointList pointList;

                        // append the starting point to the point
list,
                        // and clear it so we don't find it again
                        pointList.Append(Point(col, row));
                        image[row][col] = 0;

                        // follow the edge from the starting point
to its beginning
                        FollowEdge(row, col, image, pointList);

                        // reverse the order of the points
accumulated so far,
                        // and follow the edge from the starting
point to its end
                        pointList.Reverse();
                        FollowEdge(row, col, image, pointList);

                        // keep the point list only if it's long
enough
                        if (pointList.Size() >= minimumEdgeLength)
                        pointListList.Append(pointList);
                }
            }
        }
}

// table of row and column offsets to eight surrounding
neighbours
// (indexed anti-clockwise, starting east)
static int offsetTable[8][2] =
{
        {0, 1}, {-1, 1}, {-1, 0}, {-1, -1}, {0, -1}, {1, -1}, {1,
0}, {1,1}
```

```
};

// table of preferred neighbour checking orders for given direction
// (indexed anti-clockwise, starting east favouring non diagnals)
static int nextDirTable[8][8] =
{

     {0,  2,  6,  1,  7,  3,  4,  5),
     {2,  0,  1,  3,  7,  4,  5,  6),
     {2,  4,  0,  3,  1,  5,  6,  7},
     {4,  2,  3,  5,  1,  6,  7,  0),
     {4,  6,  2,  5,  3,  7,  0,  1},
     {6,  4,  5,  7,  3,  0,  1,  2),
     {6,  0,  4,  7,  5,  1,  2,  3},
     {0,  6,  7,  1,  5,  2,  3,  4),
};

void
FollowEdge
(
     int row,
     int col,
     Image& image,
     PointList& pointList
)
{
     Vector edgeHistory[EDGE_HISTORY_SIZE];
     int historyIndex = 0;

     for (;;)
     {
          // table of pre-computed
          // compute tangent estimate from edge history
          Vector tangent;
          for (int i = 0; i < EDGE_HISTORY_SIZE; i++)
```

```
                tangent += edgeHistory[i];

        // determine tangent angle and quantize to eight
directions
        // (direction zero corresponds to the range -PI/8 to
+PI/8, i.e east)
        double realAngle = tangent.Angle();
        int angle = (int) ((realAngle * 255) / (2 * PI) +
0.5);
                int dir = ((angle - 16 + 256) % 256) / 32;

                // try surrounding pixels, fanning out from
preferred
                // (i.e. edge) direction
                int* pNextDir = nextDirTable[dir];
                bool bFound = false;

        for (i = 0; i < 8; i++)
        {
                        // determine row and column offset for
current direction
                        int rowOffset = offsetTable[dir][0];
                        int colOffset = offsetTable[dir][1];

                        // done testing neighbours if edge pixel
found

                        if (image [row + rowOffset] [col +
colOffset] > 0)
                        {
                                // determine edge pixel address
                                Point oldPoint (col, row);
                                row += rowOffset;
                                col += colOffset;
                                Point newPoint (col, row);

                                // update edge tangent history
```

```
                                        tangent = newPoint - oldPoint;
                                        tangent.Normalize();
                                        edgeHistory[histroyIndex] = tangent;
                                        historyIndex = (historyIndex + 1) %
EDGE_HISTORY_SIZE;

                                        // append edge pixel to point list
                                        pointList.Append(newPoint);

                                        // clear edge pixel, so we don't find
it again
                                        image[row][col] = 0;
                                        bFound = true;
                                        break;
                                }
                                // determine next direction to try
                                dir = pNextDir[i];
                        }

                        // done following edge if no edge pixel found
                        if (!bFound)
                                break;
                }
}
```

The result of utilising this algorithmic component on the skeletonised edgemap is to produce a list of edges having at least a predetermined size. A suitable size was found to be a length of 20 pixel elements.

In the next step 6 of Fig. 1, Bézier curves are fitted to each of the edge lists derived from step 5. For each list of edges, a piece wise Bézier curve is fitted to the corresponding list of points. A suitable algorithm for fitting the piece wise Bézier curve is Schneider's curve fitting algorithm as set out in Schneider, P.J., "An Algorithm for Automatically Fitting Digitised Curves", in Glassner,A.S. (Ed.), Graphics Gems, Academic Press, 1990. This algorithm provides quick

convergence to a good fit which aims only for geometric continuity and not parametric continuity. Schneider's algorithm is recursive, such that if the fit is poor, is sub-divides the curve at the point of maximum error and fits the curves to the two halves separately. Next an estimate of the tangent at the split point is derived using only the two points on either side of the split point. For dense point sets, this tends to amplify the local noise. An improved quality of curve fitting can be alternatively undertaken by using points further away from the split point as the basis for the tangent.

In the next steps 7 of Fig. 1, the curves are offset from the primary curve list by half a desired "brush stroke width". The offsetting occurring on both sides of the primary curve list with the result being two curves approximately one stroke width apart from one another which run parallel to and on either side of the original primary curve.

The following algorithm is utilized to generate a piece wise Bézier curves which are approximately parallel to a specified piece wise Bézier curves and includes the steps.

i. Create an empty point list.

ii. Create and empty tangent (vector) list.

iii. Evaluate selected points on each curve segment making up the piece-wise curve and offset them by the specified offset value. Append the offset points to the point list, and their corresponding tangents to the tangent list. This process is described below with reference to Fig. 2 and 3.

iv. Fit a piece-wise Bézier curve to the resultant point list. Rather than estimating tangents during the curve-fitting process, use the exact tangents associated with the offset points.

Offset each curve segment as follows:

i. Evaluate the curve value, normalised tangent and normalised normal normalised to the size of the image for a set of evenly-spaced parameter value between (and including) 0.0 and 1.0 (eg. a spacing of 0.25).

ii. Scale the normals by the specified offset value.

iii. Construct line segments using the curve points and

scaled normals.

iv. If any two line segments intersect, eliminate the point associated with one of them.

v. Append the surviving points to the point list, and append their corresponding tangents to the tangent list. Only append the point associated with parameter value 1.0 if the segment in question is the last in the piece-wise curve, otherwise it will duplicate the point associated with parameter value 0.0 of the next segment.

The process of offsetting each curve segment can proceed as following:

1. Firstly, for a set of evenly spaced parameter values on the Bézier curve between (and including) 0.0 and 1.0, for each parameter value PN (Fig. 3) the curve value 30 a normalised tangent 31 and normalised normal 32 are calculated.

2. Next, the normals 32 are scaled 34 by a specified offset value.

3. Next a line segment from the point 30 to a point 36, which is at the end of the scaled normal 34 is calculated.

4. Next, the line segment 30, 36 is checked against corresponding line segments for all other points on the curve eg. 38, 39. If any two line segments intersect, one of the points 36 is discarded.

5. The surviving points are appended to the point list and their corresponding tangents are appended to the tangent list. The point associated with the parameter value 1.0 is appended only if the segment in question is the last in the piece-wise curve segment. Otherwise, it will duplicate the point associated with the parameter value 0.0 of the next segment.

Turning to Fig. 4, the end result of the offset of curves in accordance with step 7 of Fig. 1 is to produce for a series of Bézier curve segments C1, C2 etc. Firstly, a series of parametrically spaced points, P1 - P5. Next, the normalisation points N1 - N5 are produced (corresponding through to point 36 of Fig. 3), for each of the points P1 - P5. Next, the resultant piece-wise Bézier curve segment 40 is produced by

utilising the points in 1 - N5. This process is then repeated for the opposite curve comprising the points N6 - N10 and curve 41. This process is then repeated for each of the subsequent piece-wise curves C2 etc. The result is the two curves of 40, 41 being substantially parallel to one another and having a spaced apart width of approximately one brush stroke.

Next, a series of brush strokes are placed into the output image along the curves. The strokes are oriented in accordance with the curve tangent direction. Each brush stroke is defined to have a foot print which defines where it may not overlap with other brush strokes. A brush stroke may only be place along the curve if its foot print does not conflict with the foot prints already present in the output image. Any curves that do not have any brush strokes placed along them are discarded and the process of steps 7 and 8 are iterated in a slightly modified form until no curves are left. The slightly modified form of step 7 is to offset the curves by one brush stroke in the outward direction rather than the half brush stroke necessary when offsetting curves from the curve C1 of Fig. 4.

It has been found by utilisation of the above method that the result produced consists of a series of brush strokes which emanate from objects of interest within the image.

Subsequent to covering the image with brush strokes of a given size, further processing steps can be undertaken with smaller and smaller brush strokes and increasing derivative threshold levels so as to more accurately "brush stroke" important features in the image. Such a technique is similar to that used by van Gogh in certain portions of his images where details are required.

It would be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiment without departing from the spirit or scope of the invention as broadly described. The present embodiment is, therefore, to be considered in all respects to be illustrative and not restrictive.

Ink Jet Technologies

The embodiments of the invention use an ink jet printer type device. Of course many different devices could be used. However presently popular ink jet printing technologies are unlikely to be suitable.

The most significant problem with thermal inkjet is power consumption. This is approximately 100 times that required for high speed, and stems from the energy-inefficient means of drop ejection. This involves the rapid boiling of water to produce a vapor bubble which expels the ink. Water has a very high heat capacity, and must be superheated in thermal inkjet applications. This leads to an efficiency of around 0.02%, from electricity input to drop momentum (and increased surface area) out.

The most significant problem with piezoelectric inkjet is size and cost. Piezoelectric crystals have a very small deflection at reasonable drive voltages, and therefore require a large area for each nozzle. Also, each piezoelectric actuator must be connected to its drive circuit on a separate substrate. This is not a significant problem at the current limit of around 300 nozzles per print head, but is a major impediment to the fabrication of pagewide print heads with 19,200 nozzles.

Ideally, the inkjet technologies used meet the stringent requirements of in-camera digital color printing and other high quality, high speed, low cost printing applications. To meet the requirements of digital photography, new inkjet technologies have been created. The target features include:

low power (less than 10 Watts)
high resolution capability (1,600 dpi or more)
photographic quality output
low manufacturing cost
small size (pagewidth times minimum cross section)
high speed (< 2 seconds per page).

All of these features can be met or exceeded by the inkjet systems described below with differing levels of difficulty. 45 different inkjet technologies have been developed by the

Assignee to give a wide range of choices for high volume manufacture. These technologies form part of separate applications assigned to the present Assignee as set out in the table below.

The inkjet designs shown here are suitable for a wide range of digital printing systems, from battery powered one-time use digital cameras, through to desktop and network printers, and through to commercial printing systems

For ease of manufacture using standard process equipment, the print head is designed to be a monolithic 0.5 micron CMOS chip with MEMS post processing. For color photographic applications, the print head is 100 mm long, with a width which depends upon the inkjet type. The smallest print head designed is IJ38, which is 0.35 mm wide, giving a chip area of 35 square mm. The print heads each contain 19,200 nozzles plus data and control circuitry.

Ink is supplied to the back of the print head by injection molded plastic ink channels. The molding requires 50 micron features, which can be created using a lithographically micromachined insert in a standard injection molding tool. Ink flows through holes etched through the wafer to the nozzle chambers fabricated on the front surface of the wafer. The print head is connected to the camera circuitry by tape automated bonding.

Cross-Referenced Applications

The following table is a guide to cross-referenced patent applications filed concurrently herewith and discussed hereinafter with the reference being utilized in subsequent tables when referring to a particular case:

Docket No.	Reference	Title
IJ01US	IJ01	Radiant Plunger Ink Jet Printer
IJ02US	IJ02	Electrostatic Ink Jet Printer
IJ03US	IJ03	Planar Thermoelastic Bend Actuator Ink Jet
IJ04US	IJ04	Stacked Electrostatic Ink Jet Printer
IJ05US	IJ05	Reverse Spring Lever Ink Jet Printer
IJ06US	IJ06	Paddle Type Ink Jet Printer
IJ07US	IJ07	Permanent Magnet Electromagnetic Ink Jet Printer
IJ08US	IJ08	Planar Swing Grill Electromagnetic Ink Jet Printer

IJ09US	IJ09	Pump Action Refill Ink Jet Printer
IJ10US	IJ10	Pulsed Magnetic Field Ink Jet Printer
IJ11US	IJ11	Two Plate Reverse Firing Electromagnetic Ink Jet Printer
IJ12US	IJ12	Linear Stepper Actuator Ink Jet Printer
IJ13US	IJ13	Gear Driven Shutter Ink Jet Printer
IJ14US	IJ14	Tapered Magnetic Pole Electromagnetic Ink Jet Printer
IJ15US	IJ15	Linear Spring Electromagnetic Grill Ink Jet Printer
IJ16US	IJ16	Lorenz Diaphragm Electromagnetic Ink Jet Printer
IJ17US	IJ17	PTFE Surface Shooting Shuttered Oscillating Pressure Ink Jet Printer
IJ18US	IJ18	Buckle Grip Oscillating Pressure Ink Jet Printer
IJ19US	IJ19	Shutter Based Ink Jet Printer
IJ20US	IJ20	Curling Calyx Thermoelastic Ink Jet Printer
IJ21US	IJ21	Thermal Actuated Ink Jet Printer
IJ22US	IJ22	Iris Motion Ink Jet Printer
IJ23US	IJ23	Direct Firing Thermal Bend Actuator Ink Jet Printer
IJ24US	IJ24	Conductive PTFE Ben Activator Vented Ink Jet Printer
IJ25US	IJ25	Magnetostrictive Ink Jet Printer
IJ26US	IJ26	Shape Memory Alloy Ink Jet Printer
IJ27US	IJ27	Buckle Plate Ink Jet Printer
IJ28US	IJ28	Thermal Elastic Rotary Impeller Ink Jet Printer
IJ29US	IJ29	Thermoelastic Bend Actuator Ink Jet Printer
IJ30US	IJ30	Thermoelastic Bend Actuator Using PTFE and Corrugated Copper Ink Jet Printer
IJ31US	IJ31	Bend Actuator Direct Ink Supply Ink Jet Printer
IJ32US	IJ32	A High Young's Modulus Thermoelastic Ink Jet Printer
IJ33US	IJ33	Thermally actuated slotted chamber wall ink jet printer
IJ34US	IJ34	Ink Jet Printer having a thermal actuator comprising an external coiled spring
IJ35US	IJ35	Trough Container Ink Jet Printer
IJ36US	IJ36	Dual Chamber Single Vertical Actuator Ink Jet
IJ37US	IJ37	Dual Nozzle Single Horizontal Fulcrum Actuator Ink Jet
IJ38US	IJ38	Dual Nozzle Single Horizontal Actuator Ink Jet
IJ39US	IJ39	A single bend actuator cupped paddle ink jet printing device
IJ40US	IJ40	A thermally actuated ink jet printer having a series of thermal actuator units
IJ41US	IJ41	A thermally actuated ink jet printer including a tapered heater element
IJ42US	IJ42	Radial Back-Curling Thermoelastic Ink Jet
IJ43US	IJ43	Inverted Radial Back-Curling Thermoelastic Ink Jet
IJ44US	IJ44	Surface bend actuator vented ink supply ink jet printer
IJ45US	IJ45	Coil Acutuated Magnetic Plate Ink Jet Printer

<u>Tables of Drop-on-Demand Inkjets</u>

Eleven important characteristics of the fundamental operation of individual inkjet nozzles have been identified. These characteristics are largely orthogonal, and so can be

elucidated as an eleven dimensional matrix. Most of the eleven axes of this matrix include entries developed by the present assignee.

The following tables form the axes of an eleven dimensional table of inkjet types.

Actuator mechanism (18 types)
Basic operation mode (7 types)
Auxiliary mechanism (8 types)
Actuator amplification or modification method (17 types)
Actuator motion (19 types)
Nozzle refill method (4 types)
Method of restricting back-flow through inlet (10 types)
Nozzle clearing method (9 types)
Nozzle plate construction (9 types)
Drop ejection direction (5 types)
Ink type (7 types)

The complete eleven dimensional table represented by these axes contains 36.9 billion possible configurations of inkjet nozzle. While not all of the possible combinations result in a viable inkjet technology, many million configurations are viable. It is clearly impractical to elucidate all of the possible configurations. Instead, certain inkjet types have been investigated in detail. These are designated IJ01 to IJ45 above.

Other inkjet configurations can readily be derived from these 45 examples by substituting alternative configurations along one or more of the 11 axes. Most of the IJ01 to IJ45 examples can be made into inkjet print heads with characteristics superior to any currently available inkjet technology.

Where there are prior art examples known to the inventor, one or more of these examples are listed in the examples column of the tables below. The IJ01 to IJ45 series are also listed in the examples column. In some cases, a printer may be listed more than once in a table, where it shares characteristics with more than one entry.

Suitable applications include: Home printers, Office network printers, Short run digital printers, Commercial print systems, Fabric printers, Pocket printers, Internet WWW printers, Video printers, Medical imaging, Wide format printers, Notebook PC printers, Fax machines, Industrial printing systems, Photocopiers, Photographic minilabs etc.

The information associated with the aforementioned 11 dimensional matrix are set out in the following tables.

ACTUATOR MECHANISM (APPLIED ONLY TO SELECTED INK DROPS)

Actuator Mechanism	Description	Advantages	Disadvantages	Examples
Thermal bubble	An electrothermal heater heats the ink to above boiling point, transferring significant heat to the aqueous ink. A bubble nucleates and quickly forms, expelling the ink. The efficiency of the process is low, with typically less than 0.05% of the electrical energy being transformed into kinetic energy of the drop.	♦ Large force generated ♦ Simple construction ♦ No moving parts ♦ Fast operation ♦ Small chip area required for actuator	♦ High power ♦ Ink carrier limited to water ♦ Low efficiency ♦ High temperatures required ♦ High mechanical stress ♦ Unusual materials required ♦ Large drive transistors ♦ Cavitation causes actuator failure ♦ Kogation reduces bubble formation ♦ Large print heads are difficult to fabricate	♦ Canon Bubblejet 1979 Endo et al GB patent 2,007,162 ♦ Xerox heater-in-pit 1990 Hawkins et al USP 4,899,181 ♦ Hewlett-Packard TIJ 1982 Vaught et al USP 4,490,728
Piezoelectric	A piezoelectric crystal such as lead lanthanum zirconate (PZT) is electrically activated, and either expands, shears, or bends to apply pressure to the ink, ejecting drops.	♦ Low power consumption ♦ Many ink types can be used ♦ Fast operation ♦ High efficiency	♦ Very large area required for actuator ♦ Difficult to integrate with electronics ♦ High voltage drive transistors required ♦ Full pagewidth print heads impractical due to actuator size ♦ Requires electrical poling in high field strengths during manufacture	♦ Kyser et al USP 3,946,398 ♦ Zoltan USP 3,683,212 ♦ 1973 Stemme USP 3,747,120 ♦ Epson Stylus ♦ Tektronix ♦ IJ04

Electro-strictive	An electric field is used to activate electrostriction in relaxor materials such as lead lanthanum zirconate titanate (PLZT) or lead magnesium niobate (PMN).	♦ Low power consumption ♦ Many ink types can be used ♦ Low thermal expansion ♦ Electric field strength required (approx. 3.5 V/µm) can be generated without difficulty ♦ Does not require electrical poling	♦ Low maximum strain (approx. 0.01%) ♦ Large area required for actuator due to low strain ♦ Response speed is marginal (~ 10 µs) ♦ High voltage drive transistors required ♦ Full pagewidth print heads impractical due to actuator size	♦ Seiko Epson, Usui et all JP 253401/96 ♦ IJ04
Ferroelectric	An electric field is used to induce a phase transition between the antiferroelectric (AFE) and ferroelectric (FE) phase. Perovskite materials such as tin modified lead lanthanum zirconate titanate (PLZSnT) exhibit large strains of up to 1% associated with the AFE to FE phase transition.	♦ Low power consumption ♦ Many ink types can be used ♦ Fast operation (< 1 µs) ♦ Relatively high longitudinal strain ♦ High efficiency ♦ Electric field strength of around 3 V/µm can be readily provided	♦ Difficult to integrate with electronics ♦ Unusual materials such as PLZSnT are required ♦ Actuators require a large area	♦ IJ04
Electrostatic plates	Conductive plates are separated by a compressible or fluid dielectric (usually air). Upon application of a voltage, the plates attract each other and displace ink, causing drop ejection. The conductive plates may be in a comb or honeycomb structure, or stacked to increase the surface area and therefore the force.	♦ Low power consumption ♦ Many ink types can be used ♦ Fast operation	♦ Difficult to operate electrostatic devices in an aqueous environment ♦ The electrostatic actuator will normally need to be separated from the ink ♦ Very large area required to achieve high forces ♦ High voltage drive transistors may be required ♦ Full pagewidth print heads are not competitive due to actuator size	♦ IJ02, IJ04

Electrostatic pull on ink	A strong electric field is applied to the ink, whereupon electrostatic attraction accelerates the ink towards the print medium.	♦ Low current consumption ♦ Low temperature	♦ High voltage required ♦ May be damaged by sparks due to air breakdown ♦ Required field strength increases as the drop size decreases ♦ High voltage drive transistors required ♦ Electrostatic field attracts dust	♦ 1989 Saito et al, USP 4,799,068 ♦ 1989 Miura et al, USP 4,810,954 ♦ Tone-jet
Permanent magnet electro-magnetic	An electromagnet directly attracts a permanent magnet, displacing ink and causing drop ejection. Rare earth magnets with a field strength around 1 Tesla can be used. Examples are: Samarium Cobalt (SaCo) and magnetic materials in the neodymium iron boron family (NdFeB, NdDyFeBNb, NdDyFeB, etc)	♦ Low power consumption ♦ Many ink types can be used ♦ Fast operation ♦ High efficiency ♦ Easy extension from single nozzles to pagewidth print heads	♦ Complex fabrication ♦ Permanent magnetic material such as Neodymium Iron Boron (NdFeB) required. ♦ High local currents required ♦ Copper metalization should be used for long electromigration lifetime and low resistivity ♦ Pigmented inks are usually infeasible ♦ Operating temperature limited to the Curie temperature (around 540 K)	♦ IJ07, IJ10
Soft magnetic core electro-magnetic	A solenoid induced a magnetic field in a soft magnetic core or yoke fabricated from a ferrous material such as electroplated iron alloys such as CoNiFe [1], CoFe, or NiFe alloys. Typically, the soft magnetic material is in two parts, which are normally held apart by a spring. When the solenoid is actuated, the two parts attract, displacing the ink.	♦ Low power consumption ♦ Many ink types can be used ♦ Fast operation ♦ High efficiency ♦ Easy extension from single nozzles to pagewidth print heads	♦ Complex fabrication ♦ Materials not usually present in a CMOS fab such as NiFe, CoNiFe, or CoFe are required ♦ High local currents required ♦ Copper metalization should be used for long electromigration lifetime and low resistivity ♦ Electroplating is required ♦ High saturation flux density is required (2.0-2.1 T is achievable with CoNiFe [1])	♦ IJ01, IJ05, IJ08, IJ10 ♦ IJ12, IJ14, IJ15, IJ17

Magnetic Lorenz force	The Lorenz force acting on a current carrying wire in a magnetic field is utilized. This allows the magnetic field to be supplied externally to the print head, for example with rare earth permanent magnets. Only the current carrying wire need be fabricated on the print-head, simplifying materials requirements.	♦ Low power consumption ♦ Many ink types can be used ♦ Fast operation ♦ High efficiency ♦ Easy extension from single nozzles to pagewidth print heads	♦ Force acts as a twisting motion ♦ Typically, only a quarter of the solenoid length provides force in a useful direction ♦ High local currents required ♦ Copper metalization should be used for long electromigration lifetime and low resistivity ♦ Pigmented inks are usually infeasible	♦ IJ06, IJ11, IJ13, IJ16
Magneto-striction	The actuator uses the giant magnetostrictive effect of materials such as Terfenol-D (an alloy of terbium, dysprosium and iron developed at the Naval Ordnance Laboratory, hence Ter-Fe-NOL). For best efficiency, the actuator should be pre-stressed to approx. 8 MPa.	♦ Many ink types can be used ♦ Fast operation ♦ Easy extension from single nozzles to pagewidth print heads ♦ High force is available	♦ Force acts as a twisting motion ♦ Unusual materials such as Terfenol-D are required ♦ High local currents required ♦ Copper metalization should be used for long electromigration lifetime and low resistivity ♦ Pre-stressing may be required	♦ Fischenbeck, USP 4,032,929 ♦ IJ25
Surface tension reduction	Ink under positive pressure is held in a nozzle by surface tension. The surface tension of the ink is reduced below the bubble threshold, causing the ink to egress from the nozzle.	♦ Low power consumption ♦ Simple construction ♦ No unusual materials required in fabrication ♦ High efficiency ♦ Easy extension from single nozzles to pagewidth print heads	♦ Requires supplementary force to effect drop separation ♦ Requires special ink surfactants ♦ Speed may be limited by surfactant properties	♦ Silverbrook, EP 0771 658 A2 and related patent applications

Viscosity reduction	The ink viscosity is locally reduced to select which drops are to be ejected. A viscosity reduction can be achieved electrothermally with most inks, but special inks can be engineered for a 100:1 viscosity reduction.	♦ Simple construction ♦ No unusual materials required in fabrication ♦ Easy extension from single nozzles to pagewidth print heads	♦ Requires supplementary force to effect drop separation ♦ Requires special ink viscosity properties ♦ High speed is difficult to achieve ♦ Requires oscillating ink pressure ♦ A high temperature difference (typically 80 degrees) is required	♦ Silverbrook, EP 0771 658 A2 and related patent applications
Acoustic	An acoustic wave is generated and focussed upon the drop ejection region.	♦ Can operate without a nozzle plate	♦ Complex drive circuitry ♦ Complex fabrication ♦ Low efficiency ♦ Poor control of drop position ♦ Poor control of drop volume	♦ 1993 Hadimioglu et al, EUP 550,192 ♦ 1993 Elrod et al, EUP 572,220
Thermoelastic bend actuator	An actuator which relies upon differential thermal expansion upon Joule heating is used.	♦ Low power consumption ♦ Many ink types can be used ♦ Simple planar fabrication ♦ Small chip area required for each actuator ♦ Fast operation ♦ High efficiency ♦ CMOS compatible voltages and currents ♦ Standard MEMS processes can be used ♦ Easy extension from single nozzles to pagewidth print heads	♦ Efficient aqueous operation requires a thermal insulator on the hot side ♦ Corrosion prevention can be difficult ♦ Pigmented inks may be infeasible, as pigment particles may jam the bend actuator	♦ IJ03, IJ09, IJ17, IJ18 ♦ IJ19, IJ20, IJ21, IJ22 ♦ IJ23, IJ24, IJ27, IJ28 ♦ IJ29, IJ30, IJ31, IJ32 ♦ IJ33, IJ34, IJ35, IJ36 ♦ IJ37, IJ38 ,IJ39, IJ40 ♦ IJ41

High CTE thermoelastic actuator	A material with a very high coefficient of thermal expansion (CTE) such as polytetrafluoroethylene (PTFE) is used. As high CTE materials are usually non-conductive, a heater fabricated from a conductive material is incorporated. A 50 µm long PTFE bend actuator with polysilicon heater and 15 mW power input can provide 180 µN force and 10 µm deflection. Actuator motions include: 1) Bend 2) Push 3) Buckle 4) Rotate	♦ High force can be generated ♦ PTFE is a candidate for low dielectric constant insulation in ULSI ♦ Very low power consumption ♦ Many ink types can be used ♦ Simple planar fabrication ♦ Small chip area required for each actuator ♦ Fast operation ♦ High efficiency ♦ CMOS compatible voltages and currents ♦ Easy extension from single nozzles to pagewidth print heads	♦ Requires special material (e.g. PTFE) ♦ Requires a PTFE deposition process, which is not yet standard in ULSI fabs ♦ PTFE deposition cannot be followed with high temperature (above 350 °C) processing ♦ Pigmented inks may be infeasible, as pigment particles may jam the bend actuator	♦ IJ09, IJ17, IJ18, IJ20 ♦ IJ21, IJ22, IJ23, IJ24 ♦ IJ27, IJ28, IJ29, IJ30 ♦ IJ31, IJ42, IJ43, IJ44
Conductive polymer thermoelastic actuator	A polymer with a high coefficient of thermal expansion (such as PTFE) is doped with conducting substances to increase its conductivity to about 3 orders of magnitude below that of copper. The conducting polymer expands when resistively heated. Examples of conducting dopants include: 1) Carbon nanotubes 2) Metal fibers 3) Conductive polymers such as doped polythiophene 4) Carbon granules	♦ High force can be generated ♦ Very low power consumption ♦ Many ink types can be used ♦ Simple planar fabrication ♦ Small chip area required for each actuator ♦ Fast operation ♦ High efficiency ♦ CMOS compatible voltages and currents ♦ Easy extension from single nozzles to pagewidth print heads	♦ Requires special materials development (High CTE conductive polymer) ♦ Requires a PTFE deposition process, which is not yet standard in ULSI fabs ♦ PTFE deposition cannot be followed with high temperature (above 350 °C) processing ♦ Evaporation and CVD deposition techniques cannot be used ♦ Pigmented inks may be infeasible, as pigment particles may jam the bend actuator	♦ IJ24

Shape memory alloy	A shape memory alloy such as TiNi (also known as Nitinol - Nickel Titanium alloy developed at the Naval Ordnance Laboratory) is thermally switched between its weak martensitic state and its high stiffness austenic state. The shape of the actuator in its martensitic state is deformed relative to the austenic shape. The shape change causes ejection of a drop.	♦ High force is available (stresses of hundreds of MPa) ♦ Large strain is available (more than 3%) ♦ High corrosion resistance ♦ Simple construction ♦ Easy extension from single nozzles to pagewidth print heads ♦ Low voltage operation	♦ Fatigue limits maximum number of cycles ♦ Low strain (1%) is required to extend fatigue resistance ♦ Cycle rate limited by heat removal ♦ Requires unusual materials (TiNi) ♦ The latent heat of transformation must be provided ♦ High current operation ♦ Requires pre-stressing to distort the martensitic state	♦ IJ26
Linear Magnetic Actuator	Linear magnetic actuators include the Linear Induction Actuator (LIA), Linear Permanent Magnet Synchronous Actuator (LPMSA), Linear Reluctance Synchronous Actuator (LRSA), Linear Switched Reluctance Actuator (LSRA), and the Linear Stepper Actuator (LSA).	♦ Linear Magnetic actuators can be constructed with high thrust, long travel, and high efficiency using planar semiconductor fabrication techniques ♦ Long actuator travel is available ♦ Medium force is available ♦ Low voltage operation	♦ Requires unusual semiconductor materials such as soft magnetic alloys (e.g. CoNiFe [1]) ♦ Some varieties also require permanent magnetic materials such as Neodymium iron boron (NdFeB) ♦ Requires complex multi-phase drive circuitry ♦ High current operation	♦ IJ12

BASIC OPERATION MODE

Operational mode	Description	Advantages	Disadvantages	Examples
Actuator directly pushes ink	This is the simplest mode of operation: the actuator directly supplies sufficient kinetic energy to expel the drop. The drop must have a sufficient velocity to overcome the surface tension.	♦ Simple operation ♦ No external fields required ♦ Satellite drops can be avoided if drop velocity is less than 4 m/s ♦ Can be efficient, depending upon the actuator used	♦ Drop repetition rate is usually limited to less than 10 KHz. However, this is not fundamental to the method, but is related to the refill method normally used ♦ All of the drop kinetic energy must be provided by the actuator ♦ Satellite drops usually form if drop velocity is greater than 4.5 m/s	♦ Thermal inkjet ♦ Piezoelectric inkjet ♦ IJ01, IJ02, IJ03, IJ04 ♦ IJ05, IJ06, IJ07, IJ09 ♦ IJ11, IJ12, IJ14, IJ16 ♦ IJ20, IJ22, IJ23, IJ24 ♦ IJ25, IJ26, IJ27, IJ28 ♦ IJ29, IJ30, IJ31, IJ32 ♦ IJ33, IJ34, IJ35, IJ36 ♦ IJ37, IJ38, IJ39, IJ40 ♦ IJ41, IJ42, IJ43, IJ44
Proximity	The drops to be printed are selected by some manner (e.g. thermally induced surface tension reduction of pressurized ink). Selected drops are separated from the ink in the nozzle by contact with the print medium or a transfer roller.	♦ Very simple print head fabrication can be used ♦ The drop selection means does not need to provide the energy required to separate the drop from the nozzle	♦ Requires close proximity between the print head and the print media or transfer roller ♦ May require two print heads printing alternate rows of the image ♦ Monolithic color print heads are difficult	♦ Silverbrook, EP 0771 658 A2 and related patent applications
Electrostatic pull on ink	The drops to be printed are selected by some manner (e.g. thermally induced surface tension reduction of pressurized ink). Selected drops are separated from the ink in the nozzle by a strong electric field.	♦ Very simple print head fabrication can be used ♦ The drop selection means does not need to provide the energy required to separate the drop from the nozzle	♦ Requires very high electrostatic field ♦ Electrostatic field for small nozzle sizes is above air breakdown ♦ Electrostatic field may attract dust	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Tone-Jet

Magnetic pull on ink	The drops to be printed are selected by some manner (e.g. thermally induced surface tension reduction of pressurized ink). Selected drops are separated from the ink in the nozzle by a strong magnetic field acting on the magnetic ink.	♦ Very simple print head fabrication can be used ♦ The drop selection means does not need to provide the energy required to separate the drop from the nozzle	♦ Requires magnetic ink ♦ Ink colors other than black are difficult ♦ Requires very high magnetic fields	♦ Silverbrook, EP 0771 658 A2 and related patent applications
Shutter	The actuator moves a shutter to block ink flow to the nozzle. The ink pressure is pulsed at a multiple of the drop ejection frequency.	♦ High speed (>50 KHz) operation can be achieved due to reduced refill time ♦ Drop timing can be very accurate ♦ The actuator energy can be very low	♦ Moving parts are required ♦ Requires ink pressure modulator ♦ Friction and wear must be considered ♦ Stiction is possible	♦ IJ13, IJ17, IJ21
Shuttered grill	The actuator moves a shutter to block ink flow through a grill to the nozzle. The shutter movement need only be equal to the width of the grill holes.	♦ Actuators with small travel can be used ♦ Actuators with small force can be used ♦ High speed (>50 KHz) operation can be achieved	♦ Moving parts are required ♦ Requires ink pressure modulator ♦ Friction and wear must be considered ♦ Stiction is possible	♦ IJ08, IJ15, IJ18, IJ19
Pulsed magnetic pull on ink pusher	A pulsed magnetic field attracts an 'ink pusher' at the drop ejection frequency. An actuator controls a catch, which prevents the ink pusher from moving when a drop is not to be ejected.	♦ Extremely low energy operation is possible ♦ No heat dissipation problems	♦ Requires an external pulsed magnetic field ♦ Requires special materials for both the actuator and the ink pusher ♦ Complex construction	♦ IJ10

AUXILIARY MECHANISM (APPLIED TO ALL NOZZLES)

Auxiliary Mechanism	Description	Advantages	Disadvantages	Examples
None	The actuator directly fires the ink drop, and there is no external field or other mechanism required.	♦ Simplicity of construction ♦ Simplicity of operation ♦ Small physical size	♦ Drop ejection energy must be supplied by individual nozzle actuator	♦ Most inkjets, including piezoelectric and thermal bubble. ♦ IJ01- IJ07, IJ09, IJ11 ♦ IJ12, IJ14, IJ20, IJ22 ♦ IJ23-IJ45
Oscillating ink pressure (including acoustic stimulation)	The ink pressure oscillates, providing much of the drop ejection energy. The actuator selects which drops are to be fired by selectively blocking or enabling nozzles. The ink pressure oscillation may be achieved by vibrating the print head, or preferably by an actuator in the ink supply.	♦ Oscillating ink pressure can provide a refill pulse, allowing higher operating speed ♦ The actuators may operate with much lower energy ♦ Acoustic lenses can be used to focus the sound on the nozzles	♦ Requires external ink pressure oscillator ♦ Ink pressure phase and amplitude must be carefully controlled ♦ Acoustic reflections in the ink chamber must be designed for	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ IJ08, IJ13, IJ15, IJ17 ♦ IJ18, IJ19, IJ21
Media proximity	The print head is placed in close proximity to the print medium. Selected drops protrude from the print head further than unselected drops, and contact the print medium. The drop soaks into the medium fast enough to cause drop separation.	♦ Low power ♦ High accuracy ♦ Simple print head construction	♦ Precision assembly required ♦ Paper fibers may cause problems ♦ Cannot print on rough substrates	♦ Silverbrook, EP 0771 658 A2 and related patent applications

Transfer roller	Drops are printed to a transfer roller instead of straight to the print medium. A transfer roller can also be used for proximity drop separation.	♦ High accuracy ♦ Wide range of print substrates can be used ♦ Ink can be dried on the transfer roller	♦ Bulky ♦ Expensive ♦ Complex construction	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Tektronix hot melt piezoelectric inkjet ♦ Any of the IJ series
Electrostatic	An electric field is used to accelerate selected drops towards the print medium.	♦ Low power ♦ Simple print head construction	♦ Field strength required for separation of small drops is near or above air breakdown	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Tone-Jet
Direct magnetic field	A magnetic field is used to accelerate selected drops of magnetic ink towards the print medium.	♦ Low power ♦ Simple print head construction	♦ Requires magnetic ink ♦ Requires strong magnetic field	♦ Silverbrook, EP 0771 658 A2 and related patent applications
Cross magnetic field	The print head is placed in a constant magnetic field. The Lorenz force in a current carrying wire is used to move the actuator.	♦ Does not require magnetic materials to be integrated in the print head manufacturing process	♦ Requires external magnet ♦ Current densities may be high, resulting in electromigration problems	♦ IJ06, IJ16
Pulsed magnetic field	A pulsed magnetic field is used to cyclically attract a paddle, which pushes on the ink. A small actuator moves a catch, which selectively prevents the paddle from moving.	♦ Very low power operation is possible ♦ Small print head size	♦ Complex print head construction ♦ Magnetic materials required in print head	♦ IJ10

ACTUATOR AMPLIFICATION OR MODIFICATION METHOD

Actuator amplification	Description	Advantages	Disadvantages	Examples
None	No actuator mechanical amplification is used. The actuator directly drives the drop ejection process.	♦ Operational simplicity	♦ Many actuator mechanisms have insufficient travel, or insufficient force, to efficiently drive the drop ejection process	♦ Thermal Bubble Inkjet ♦ IJ01, IJ02, IJ06, IJ07 ♦ IJ16, IJ25, IJ26
Differential expansion bend actuator	An actuator material expands more on one side than on the other. The expansion may be thermal, piezoelectric, magnetostrictive, or other mechanism.	♦ Provides greater travel in a reduced print head area ♦ The bend actuator converts a high force low travel actuator mechanism to high travel, lower force mechanism.	♦ High stresses are involved ♦ Care must be taken that the materials do not delaminate ♦ Residual bend resulting from high temperature or high stress during formation	♦ Piezoelectric ♦ IJ03, IJ09, IJ17-IJ24 ♦ IJ27, IJ29-IJ39, IJ42, ♦ IJ43, IJ44
Transient bend actuator	A trilayer bend actuator where the two outside layers are identical. This cancels bend due to ambient temperature and residual stress. The actuator only responds to transient heating of one side or the other.	♦ Very good temperature stability ♦ High speed, as a new drop can be fired before heat dissipates ♦ Cancels residual stress of formation	♦ High stresses are involved ♦ Care must be taken that the materials do not delaminate	♦ IJ40, IJ41
Actuator stack	A series of thin actuators are stacked. This can be appropriate where actuators require high electric field strength, such as electrostatic and piezoelectric actuators.	♦ Increased travel ♦ Reduced drive voltage	♦ Increased fabrication complexity ♦ Increased possibility of short circuits due to pinholes	♦ Some piezoelectric ink jets ♦ IJ04
Multiple actuators	Multiple smaller actuators are used simultaneously to move the ink. Each actuator need provide only a portion of the force required.	♦ Increases the force available from an actuator ♦ Multiple actuators can be positioned to control ink flow accurately	♦ Actuator forces may not add linearly, reducing efficiency	♦ IJ12, IJ13, IJ18, IJ20 ♦ IJ22, IJ28, IJ42, IJ43

Linear Spring	A linear spring is used to transform a motion with small travel and high force into a longer travel, lower force motion.	♦ Matches low travel actuator with higher travel requirements ♦ Non-contact method of motion transformation	♦ Requires print head area for the spring	♦ IJ15
Reverse spring	The actuator loads a spring. When the actuator is turned off, the spring releases. This can reverse the force/distance curve of the actuator to make it compatible with the force/time requirements of the drop ejection.	♦ Better coupling to the ink	♦ Fabrication complexity ♦ High stress in the spring	♦ IJ05, IJ11
Coiled actuator	A bend actuator is coiled to provide greater travel in a reduced chip area.	♦ Increases travel ♦ Reduces chip area ♦ Planar implementations are relatively easy to fabricate.	♦ Generally restricted to planar implementations due to extreme fabrication difficulty in other orientations.	♦ IJ17, IJ21, IJ34, IJ35
Flexure bend actuator	A bend actuator has a small region near the fixture point, which flexes much more readily than the remainder of the actuator. The actuator flexing is effectively converted from an even coiling to an angular bend, resulting in greater travel of the actuator tip.	♦ Simple means of increasing travel of a bend actuator	♦ Care must be taken not to exceed the elastic limit in the flexure area ♦ Stress distribution is very uneven ♦ Difficult to accurately model with finite element analysis	♦ IJ10, IJ19, IJ33
Gears	Gears can be used to increase travel at the expense of duration. Circular gears, rack and pinion, ratchets, and other gearing methods can be used.	♦ Low force, low travel actuators can be used ♦ Can be fabricated using standard surface MEMS processes	♦ Moving parts are required ♦ Several actuator cycles are required ♦ More complex drive electronics ♦ Complex construction ♦ Friction, friction, and wear are possible	♦ IJ13

Catch	The actuator controls a small catch. The catch either enables or disables movement of an ink pusher that is controlled in a bulk manner.	♦ Very low actuator energy ♦ Very small actuator size	♦ Complex construction ♦ Requires external force ♦ Unsuitable for pigmented inks	♦ IJ10
Buckle plate	A buckle plate can be used to change a slow actuator into a fast motion. It can also convert a high force, low travel actuator into a high travel, medium force motion.	♦ Very fast movement achievable	♦ Must stay within elastic limits of the materials for long device life ♦ High stresses involved ♦ Generally high power requirement	♦ S. Hirata et al, "An Ink-jet Head …", Proc. IEEE MEMS, Feb. 1996, pp 418-423. ♦ IJ18, IJ27
Tapered magnetic pole	A tapered magnetic pole can increase travel at the expense of force.	♦ Linearizes the magnetic force/distance curve	♦ Complex construction	♦ IJ14
Lever	A lever and fulcrum is used to transform a motion with small travel and high force into a motion with longer travel and lower force. The lever can also reverse the direction of travel.	♦ Matches low travel actuator with higher travel requirements ♦ Fulcrum area has no linear movement, and can be used for a fluid seal	♦ High stress around the fulcrum	♦ IJ32, IJ36, IJ37
Rotary impeller	The actuator is connected to a rotary impeller. A small angular deflection of the actuator results in a rotation of the impeller vanes, which push the ink against stationary vanes and out of the nozzle.	♦ High mechanical advantage ♦ The ratio of force to travel of the actuator can be matched to the nozzle requirements by varying the number of impeller vanes	♦ Complex construction ♦ Unsuitable for pigmented inks	♦ IJ28
Acoustic lens	A refractive or diffractive (e.g. zone plate) acoustic lens is used to concentrate sound waves.	♦ No moving parts	♦ Large area required ♦ Only relevant for acoustic ink jets	♦ 1993 Hadimioglu et al, EUP 550,192 ♦ 1993 Elrod et al, EUP 572,220
Sharp conductive point	A sharp point is used to concentrate an electrostatic field.	♦ Simple construction	♦ Difficult to fabricate using standard VLSI processes for a surface ejecting ink-jet ♦ Only relevant for electrostatic ink jets	♦ Tone-jet

ACTUATOR MOTION

Actuator motion	Description	Advantages	Disadvantages	Examples
Volume expansion	The volume of the actuator changes, pushing the ink in all directions.	♦ Simple construction in the case of thermal ink jet	♦ High energy is typically required to achieve volume expansion. This leads to thermal stress, cavitation, and kogation in thermal ink jet implementations	♦ Hewlett-Packard Thermal Inkjet ♦ Canon Bubblejet
Linear, normal to chip surface	The actuator moves in a direction normal to the print head surface. The nozzle is typically in the line of movement.	♦ Efficient coupling to ink drops ejected normal to the surface	♦ High fabrication complexity may be required to achieve perpendicular motion	♦ IJ01, IJ02, IJ04, IJ07 ♦ IJ11, IJ14
Linear, parallel to chip surface	The actuator moves parallel to the print head surface. Drop ejection may still be normal to the surface.	♦ Suitable for planar fabrication	♦ Fabrication complexity ♦ Friction ♦ Stiction	♦ IJ12, IJ13, IJ15, IJ33, ♦ IJ34, IJ35, IJ36
Membrane push	An actuator with a high force but small area is used to push a stiff membrane that is in contact with the ink.	♦ The effective area of the actuator becomes the membrane area	♦ Fabrication complexity ♦ Actuator size ♦ Difficulty of integration in a VLSI process	♦ 1982 Howkins USP 4,459,601
Rotary	The actuator causes the rotation of some element, such a grill or impeller	♦ Rotary levers may be used to increase travel ♦ Small chip area requirements	♦ Device complexity ♦ May have friction at a pivot point	♦ IJ05, IJ08, IJ13, IJ28
Bend	The actuator bends when energized. This may be due to differential thermal expansion, piezoelectric expansion, magnetostriction, or other form of relative dimensional change.	♦ A very small change in dimensions can be converted to a large motion.	♦ Requires the actuator to be made from at least two distinct layers, or to have a thermal difference across the actuator	♦ 1970 Kyser et al USP 3,946,398 ♦ 1973 Stemme USP 3,747,120 ♦ IJ03, IJ09, IJ10, IJ19 ♦ IJ23, IJ24, IJ25, IJ29 ♦ IJ30, IJ31, IJ33, IJ34 ♦ IJ35

Swivel	The actuator swivels around a central pivot. This motion is suitable where there are opposite forces applied to opposite sides of the paddle, e.g. Lorenz force.	♦ Allows operation where the net linear force on the paddle is zero ♦ Small chip area requirements	♦ Inefficient coupling to the ink motion	♦ IJ06
Straighten	The actuator is normally bent, and straightens when energized.	♦ Can be used with shape memory alloys where the austenic phase is planar	♦ Requires careful balance of stresses to ensure that the quiescent bend is accurate	♦ IJ26, IJ32
Double bend	The actuator bends in one direction when one element is energized, and bends the other way when another element is energized.	♦ One actuator can be used to power two nozzles. ♦ Reduced chip size. ♦ Not sensitive to ambient temperature	♦ Difficult to make the drops ejected by both bend directions identical. ♦ A small efficiency loss compared to equivalent single bend actuators.	♦ IJ36, IJ37, IJ38
Shear	Energizing the actuator causes a shear motion in the actuator material.	♦ Can increase the effective travel of piezoelectric actuators	♦ Not readily applicable to other actuator mechanisms	♦ 1985 Fishbeck USP 4,584,590
Radial constriction	The actuator squeezes an ink reservoir, forcing ink from a constricted nozzle.	♦ Relatively easy to fabricate single nozzles from glass tubing as macroscopic structures	♦ High force required ♦ Inefficient ♦ Difficult to integrate with VLSI processes	♦ 1970 Zoltan USP 3,683,212
Coil / uncoil	A coiled actuator uncoils or coils more tightly. The motion of the free end of the actuator ejects the ink.	♦ Easy to fabricate as a planar VLSI process ♦ Small area required, therefore low cost	♦ Difficult to fabricate for non-planar devices ♦ Poor out-of-plane stiffness	♦ IJ17, IJ21, IJ34, IJ35
Bow	The actuator bows (or buckles) in the middle when energized.	♦ Can increase the speed of travel ♦ Mechanically rigid	♦ Maximum travel is constrained ♦ High force required	♦ IJ16, IJ18, IJ27
Push-Pull	Two actuators control a shutter. One actuator pulls the shutter, and the other pushes it.	♦ The structure is pinned at both ends, so has a high out-of-plane rigidity	♦ Not readily suitable for inkjets which directly push the ink	♦ IJ18

Curl inwards	A set of actuators curl inwards to reduce the volume of ink that they enclose.	♦ Good fluid flow to the region behind the actuator increases efficiency	♦ Design complexity	♦ IJ20, IJ42
Curl outwards	A set of actuators curl outwards, pressurizing ink in a chamber surrounding the actuators, and expelling ink from a nozzle in the chamber.	♦ Relatively simple construction	♦ Relatively large chip area	♦ IJ43
Iris	Multiple vanes enclose a volume of ink. These simultaneously rotate, reducing the volume between the vanes.	♦ High efficiency ♦ Small chip area	♦ High fabrication complexity ♦ Not suitable for pigmented inks	♦ IJ22
Acoustic vibration	The actuator vibrates at a high frequency.	♦ The actuator can be physically distant from the ink	♦ Large area required for efficient operation at useful frequencies ♦ Acoustic coupling and crosstalk ♦ Complex drive circuitry ♦ Poor control of drop volume and position	♦ 1993 Hadimioglu et al, EUP 550,192 ♦ 1993 Elrod et al, EUP 572,220
None	In various ink jet designs the actuator does not move.	♦ No moving parts	♦ Various other tradeoffs are required to eliminate moving parts	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Tone-jet

NOZZLE REFILL METHOD

Nozzle refill method	Description	Advantages	Disadvantages	Examples
Surface tension	After the actuator is energized, it typically returns rapidly to its normal position. This rapid return sucks in air through the nozzle opening. The ink surface tension at the nozzle then exerts a small force restoring the meniscus to a minimum area.	♦ Fabrication simplicity ♦ Operational simplicity	♦ Low speed ♦ Surface tension force relatively small compared to actuator force ♦ Long refill time usually dominates the total repetition rate	♦ Thermal inkjet ♦ Piezoelectric inkjet ♦ IJ01-IJ07, IJ10-IJ14 ♦ IJ16, IJ20, IJ22-IJ45
Shuttered oscillating ink pressure	Ink to the nozzle chamber is provided at a pressure that oscillates at twice the drop ejection frequency. When a drop is to be ejected, the shutter is opened for 3 half cycles: drop ejection, actuator return, and refill.	♦ High speed ♦ Low actuator energy, as the actuator need only open or close the shutter, instead of ejecting the ink drop	♦ Requires common ink pressure oscillator ♦ May not be suitable for pigmented inks	♦ IJ08, IJ13, IJ15, IJ17 ♦ IJ18, IJ19, IJ21
Refill actuator	After the main actuator has ejected a drop a second (refill) actuator is energized. The refill actuator pushes ink into the nozzle chamber. The refill actuator returns slowly, to prevent its return from emptying the chamber again.	♦ High speed, as the nozzle is actively refilled	♦ Requires two independent actuators per nozzle	♦ IJ09
Positive ink pressure	The ink is held a slight positive pressure. After the ink drop is ejected, the nozzle chamber fills quickly as surface tension and ink pressure both operate to refill the nozzle.	♦ High refill rate, therefore a high drop repetition rate is possible	♦ Surface spill must be prevented ♦ Highly hydrophobic print head surfaces are required	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Alternative for: ♦ IJ01-IJ07, IJ10-IJ14 ♦ IJ16, IJ20, IJ22-IJ45

METHOD OF RESTRICTING BACK-FLOW THROUGH INLET

Inlet back-flow restriction method	Description	Advantages	Disadvantages	Examples
Long inlet channel	The ink inlet channel to the nozzle chamber is made long and relatively narrow, relying on viscous drag to reduce inlet back-flow.	♦ Design simplicity ♦ Operational simplicity ♦ Reduces crosstalk	♦ Restricts refill rate ♦ May result in a relatively large chip area ♦ Only partially effective	♦ Thermal inkjet ♦ Piezoelectric inkjet ♦ IJ42, IJ43
Positive ink pressure	The ink is under a positive pressure, so that in the quiescent state some of the ink drop already protrudes from the nozzle. This reduces the pressure in the nozzle chamber which is required to eject a certain volume of ink. The reduction in chamber pressure results in a reduction in ink pushed out through the inlet.	♦ Drop selection and separation forces can be reduced ♦ Fast refill time	♦ Requires a method (such as a nozzle rim or effective hydrophobizing, or both) to prevent flooding of the ejection surface of the print head.	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Possible operation of the following: ♦ IJ01-IJ07, IJ09- IJ12 ♦ IJ14, IJ16, IJ20, IJ22, ♦ IJ23-IJ34, IJ36- IJ41 ♦ IJ44
Baffle	One or more baffles are placed in the inlet ink flow. When the actuator is energized, the rapid ink movement creates eddies which restrict the flow through the inlet. The slower refill process is unrestricted, and does not result in eddies.	♦ The refill rate is not as restricted as the long inlet method. ♦ Reduces crosstalk	♦ Design complexity ♦ May increase fabrication complexity (e.g. Tektronix hot melt Piezoelectric print heads).	♦ HP Thermal Ink Jet ♦ Tektronix piezoelectric ink jet
Flexible flap restricts inlet	In this method recently disclosed by Canon, the expanding actuator (bubble) pushes on a flexible flap that restricts the inlet.	♦ Significantly reduces back-flow for edge-shooter thermal ink jet devices	♦ Not applicable to most inkjet configurations ♦ Increased fabrication complexity ♦ Inelastic deformation of polymer flap results in creep over extended use	♦ Canon

Inlet filter	A filter is located between the ink inlet and the nozzle chamber. The filter has a multitude of small holes or slots, restricting ink flow. The filter also removes particles which may block the nozzle.	♦ Additional advantage of ink filtration ♦ Ink filter may be fabricated with no additional process steps	♦ Restricts refill rate ♦ May result in complex construction	♦ IJ04, IJ12, IJ24, IJ27 ♦ IJ29, IJ30
Small inlet compared to nozzle	The ink inlet channel to the nozzle chamber has a substantially smaller cross section than that of the nozzle , resulting in easier ink egress out of the nozzle than out of the inlet.	♦ Design simplicity	♦ Restricts refill rate ♦ May result in a relatively large chip area ♦ Only partially effective	♦ IJ02, IJ37, IJ44
Inlet shutter	A secondary actuator controls the position of a shutter, closing off the ink inlet when the main actuator is energized.	♦ Increases speed of the ink-jet print head operation	♦ Requires separate refill actuator and drive circuit	♦ IJ09
The inlet is located behind the ink-pushing surface	The method avoids the problem of inlet back-flow by arranging the ink-pushing surface of the actuator between the inlet and the nozzle.	♦ Back-flow problem is eliminated	♦ Requires careful design to minimize the negative pressure behind the paddle	♦ IJ01, IJ03, IJ05, IJ06 ♦ IJ07, IJ10, IJ11, IJ14 ♦ IJ16, IJ22, IJ23, IJ25 ♦ IJ28, IJ31, IJ32, IJ33 ♦ IJ34, IJ35, IJ36, IJ39 ♦ IJ40, IJ41
Part of the actuator moves to shut off the inlet	The actuator and a wall of the ink chamber are arranged so that the motion of the actuator closes off the inlet.	♦ Significant reductions in back-flow can be achieved ♦ Compact designs possible	♦ Small increase in fabrication complexity	♦ IJ07, IJ20, IJ26, IJ38
Nozzle actuator does not result in ink back-flow	In some configurations of ink jet, there is no expansion or movement of an actuator which may cause ink back-flow through the inlet.	♦ Ink back-flow problem is eliminated	♦ None related to ink back-flow on actuation	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Valve-jet ♦ Tone-jet ♦ IJ08, IJ13, IJ15, IJ17 ♦ IJ18, IJ19, IJ21

Nozzle Clearing Method

Nozzle Clearing method	Description	Advantages	Disadvantages	Examples
Normal nozzle firing	All of the nozzles are fired periodically, before the ink has a chance to dry. When not in use the nozzles are sealed (capped) against air. The nozzle firing is usually performed during a special clearing cycle, after first moving the print head to a cleaning station.	♦ No added complexity on the print head	♦ May not be sufficient to displace dried ink	♦ Most ink jet systems ♦ IJ01- IJ07, IJ09-IJ12 ♦ IJ14, IJ16, IJ20, IJ22 ♦ IJ23- IJ34, IJ36-IJ45
Extra power to ink heater	In systems which heat the ink, but do not boil it under normal situations, nozzle clearing can be achieved by over-powering the heater and boiling ink at the nozzle.	♦ Can be highly effective if the heater is adjacent to the nozzle	♦ Requires higher drive voltage for clearing ♦ May require larger drive transistors	♦ Silverbrook, EP 0771 658 A2 and related patent applications
Rapid succession of actuator pulses	The actuator is fired in rapid succession. In some configurations, this may cause heat build-up at the nozzle which boils the ink, clearing the nozzle. In other situations, it may cause sufficient vibrations to dislodge clogged nozzles.	♦ Does not require extra drive circuits on the print head ♦ Can be readily controlled and initiated by digital logic	♦ Effectiveness depends substantially upon the configuration of the inkjet nozzle	♦ May be used with: ♦ IJ01-IJ07, IJ09- IJ11 ♦ IJ14, IJ16, IJ20, IJ22 ♦ IJ23-IJ25, IJ27-IJ34 ♦ IJ36-IJ45
Extra power to ink pushing actuator	Where an actuator is not normally driven to the limit of its motion, nozzle clearing may be assisted by providing an enhanced drive signal to the actuator.	♦ A simple solution where applicable	♦ Not suitable where there is a hard limit to actuator movement	♦ May be used with: ♦ IJ03, IJ09, IJ16, IJ20 ♦ IJ23, IJ24, IJ25, IJ27 ♦ IJ29, IJ30, IJ31, IJ32 ♦ IJ39, IJ40, IJ41, IJ42 ♦ IJ43, IJ44, IJ45

Acoustic resonance	An ultrasonic wave is applied to the ink chamber. This wave is of an appropriate amplitude and frequency to cause sufficient force at the nozzle to clear blockages. This is easiest to achieve if the ultrasonic wave is at a resonant frequency of the ink cavity.	♦ A high nozzle clearing capability can be achieved ♦ May be implemented at very low cost in systems which already include acoustic actuators	♦ High implementation cost if system does not already include an acoustic actuator	♦ IJ08, IJ13, IJ15, IJ17 ♦ IJ18, IJ19, IJ21
Nozzle clearing plate	A microfabricated plate is pushed against the nozzles. The plate has a post for every nozzle. The array of posts	♦ Can clear severely clogged nozzles	♦ Accurate mechanical alignment is required ♦ Moving parts are required ♦ There is risk of damage to the nozzles ♦ Accurate fabrication is required	♦ Silverbrook, EP 0771 658 A2 and related patent applications
Ink pressure pulse	The pressure of the ink is temporarily increased so that ink streams from all of the nozzles. This may be used in conjunction with actuator energizing.	♦ May be effective where other methods cannot be used	♦ Requires pressure pump or other pressure actuator ♦ Expensive ♦ Wasteful of ink	♦ May be used with all IJ series ink jets
Print head wiper	A flexible 'blade' is wiped across the print head surface. The blade is usually fabricated from a flexible polymer, e.g. rubber or synthetic elastomer.	♦ Effective for planar print head surfaces ♦ Low cost	♦ Difficult to use if print head surface is non-planar or very fragile ♦ Requires mechanical parts ♦ Blade can wear out in high volume print systems	♦ Many ink jet systems
Separate ink boiling heater	A separate heater is provided at the nozzle although the normal drop e-ection mechanism does not require it. The heaters do not require individual drive circuits, as many nozzles can be cleared simultaneously, and no imaging is required.	♦ Can be effective where other nozzle clearing methods cannot be used ♦ Can be implemented at no additional cost in some inkjet configurations	♦ Fabrication complexity	♦ Can be used with many IJ series ink jets

NOZZLE PLATE CONSTRUCTION

Nozzle plate construction	Description	Advantages	Disadvantages	Examples
Electroformed nickel	A nozzle plate is separately fabricated from electroformed nickel, and bonded to the print head chip.	♦ Fabrication simplicity	♦ High temperatures and pressures are required to bond nozzle plate ♦ Minimum thickness constraints ♦ Differential thermal expansion	♦ Hewlett Packard Thermal Inkjet
Laser ablated or drilled polymer	Individual nozzle holes are ablated by an intense UV laser in a nozzle plate, which is typically a polymer such as polyimide or polysulphone	♦ No masks required ♦ Can be quite fast ♦ Some control over nozzle profile is possible ♦ Equipment required is relatively low cost	♦ Each hole must be individually formed ♦ Special equipment required ♦ Slow where there are many thousands of nozzles per print head ♦ May produce thin burrs at exit holes	♦ Canon Bubblejet ♦ 1988 Sercel et al., SPIE, Vol. 998 Excimer Beam Applications, pp. 76-83 ♦ 1993 Watanabe et al., USP 5,208,604
Silicon micro-machined	A separate nozzle plate is micromachined from single crystal silicon, and bonded to the print head wafer.	♦ High accuracy is attainable	♦ Two part construction ♦ High cost ♦ Requires precision alignment ♦ Nozzles may be clogged by adhesive	♦ K. Bean, IEEE Transactions on Electron Devices, Vol. ED-25, No. 10, 1978, pp 1185-1195 ♦ Xerox 1990 Hawkins et al., USP 4,899,181
Glass capillaries	Fine glass capillaries are drawn from glass tubing. This method has been used for making individual nozzles, but is difficult to use for bulk manufacturing of print heads with thousands of nozzles.	♦ No expensive equipment required ♦ Simple to make single nozzles	♦ Very small nozzle sizes are difficult to form ♦ Not suited for mass production	♦ 1970 Zoltan USP 3,683,212

Monolithic, surface micro-machined using VLSI lithographic processes	The nozzle plate is deposited as a layer using standard VLSI deposition techniques. Nozzles are etched in the nozzle plate using VLSI lithography and etching.	♦ High accuracy (<1 µm) ♦ Monolithic ♦ Low cost ♦ Existing processes can be used	♦ Requires sacrificial layer under the nozzle plate to form the nozzle chamber ♦ Surface may be fragile to the touch	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ IJ01, IJ02, IJ04, IJ11 ♦ IJ12, IJ17, IJ18, IJ20 ♦ IJ22, IJ24, IJ27, IJ28 ♦ IJ29, IJ30, IJ31, IJ32 ♦ IJ33, IJ34, IJ36, IJ37 ♦ IJ38, IJ39, IJ40, IJ41 ♦ IJ42, IJ43, IJ44
Monolithic, etched through substrate	The nozzle plate is a buried etch stop in the wafer. Nozzle chambers are etched in the front of the wafer, and the wafer is thinned from the back side. Nozzles are then etched in the etch stop layer.	♦ High accuracy (<1 µm) ♦ Monolithic ♦ Low cost ♦ No differential expansion	♦ Requires long etch times ♦ Requires a support wafer	♦ IJ03, IJ05, IJ06, IJ07 ♦ IJ08, IJ09, IJ10, IJ13 ♦ IJ14, IJ15, IJ16, IJ19 ♦ IJ21, IJ23, IJ25, IJ26
No nozzle plate	Various methods have been tried to eliminate the nozzles entirely, to prevent nozzle clogging. These include thermal bubble mechanisms and acoustic lens mechanisms	♦ No nozzles to become clogged	♦ Difficult to control drop position accurately ♦ Crosstalk problems	♦ Ricoh 1995 Sekiya et al USP 5,412,413 ♦ 1993 Hadimioglu et al EUP 550,192 ♦ 1993 Elrod et al EUP 572,220
Trough	Each drop ejector has a trough through which a paddle moves. There is no nozzle plate.	♦ Reduced manufacturing complexity ♦ Monolithic	♦ Drop firing direction is sensitive to wicking.	♦ IJ35
Nozzle slit instead of individual nozzles	The elimination of nozzle holes and replacement by a slit encompassing many actuator positions reduces nozzle clogging, but increases crosstalk due to ink surface waves	♦ No nozzles to become clogged	♦ Difficult to control drop position accurately ♦ Crosstalk problems	♦ 1989 Saito et al USP 4,799,068

DROP EJECTION DIRECTION

Ejection direction	Description	Advantages	Disadvantages	Examples
Edge ('edge shooter')	Ink flow is along the surface of the chip, and ink drops are ejected from the chip edge.	♦ Simple construction ♦ No silicon etching required ♦ Good heat sinking via substrate ♦ Mechanically strong ♦ Ease of chip handing	♦ Nozzles limited to edge ♦ High resolution is difficult ♦ Fast color printing requires one print head per color	♦ Canon Bubblejet 1979 Endo et al GB patent 2,007,162 ♦ Xerox heater-in-pit 1990 Hawkins et al USP 4,899,181 ♦ Tone-jet
Surface ('roof shooter')	Ink flow is along the surface of the chip, and ink drops are ejected from the chip surface, normal to the plane of the chip.	♦ No bulk silicon etching required ♦ Silicon can make an effective heat sink ♦ Mechanical strength	♦ Maximum ink flow is severely restricted	♦ Hewlett-Packard TIJ 1982 Vaught et al USP 4,490,728 ♦ IJ02, IJ11, IJ12, IJ20 ♦ IJ22
Through chip, forward ('up shooter')	Ink flow is through the chip, and ink drops are ejected from the front surface of the chip.	♦ High ink flow ♦ Suitable for pagewidth print ♦ High nozzle packing density therefore low manufacturing cost	♦ Requires bulk silicon etching	♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ IJ04, IJ17, IJ18, IJ24 ♦ IJ27-IJ45
Through chip, reverse ('down shooter')	Ink flow is through the chip, and ink drops are ejected from the rear surface of the chip.	♦ High ink flow ♦ Suitable for pagewidth print ♦ High nozzle packing density therefore low manufacturing cost	♦ Requires wafer thinning ♦ Requires special handling during manufacture	♦ IJ01, IJ03, IJ05, IJ06 ♦ IJ07, IJ08, IJ09, IJ10 ♦ IJ13, IJ14, IJ15, IJ16 ♦ IJ19, IJ21, IJ23, IJ25 ♦ IJ26
Through actuator	Ink flow is through the actuator, which is not fabricated as part of the same substrate as the drive transistors.	♦ Suitable for piezoelectric print heads	♦ Pagewidth print heads require several thousand connections to drive circuits ♦ Cannot be manufactured in standard CMOS fabs ♦ Complex assembly required	♦ Epson Stylus ♦ Tektronix hot melt piezoelectric ink jets

INK TYPE

Ink type	Description	Advantages	Disadvantages	Examples
Aqueous, dye	Water based ink which typically contains: water, dye, surfactant, humectant, and biocide. Modern ink dyes have high water-fastness, light fastness	♦ Environmentally friendly ♦ No odor	♦ Slow drying ♦ Corrosive ♦ Bleeds on paper ♦ May strikethrough ♦ Cockles paper	♦ Most existing inkjets ♦ All IJ series ink jets ♦ Silverbrook, EP 0771 658 A2 and related patent applications
Aqueous, pigment	Water based ink which typically contains: water, pigment, surfactant, humectant, and biocide. Pigments have an advantage in reduced bleed, wicking and strikethrough.	♦ Environmentally friendly ♦ No odor ♦ Reduced bleed ♦ Reduced wicking ♦ Reduced strikethrough	♦ Slow drying ♦ Corrosive ♦ Pigment may clog nozzles ♦ Pigment may clog actuator mechanisms ♦ Cockles paper	♦ IJ02, IJ04, IJ21, IJ26 ♦ IJ27, IJ30 ♦ Silverbrook, EP 0771 658 A2 and related patent applications ♦ Piezoelectric ink-jets ♦ Thermal ink jets (with significant restrictions)
Methyl Ethyl Ketone (MEK)	MEK is a highly volatile solvent used for industrial printing on difficult surfaces such as aluminum cans.	♦ Very fast drying ♦ Prints on various substrates such as metals and plastics	♦ Odorous ♦ Flammable	♦ All IJ series ink jets
Alcohol (ethanol, 2-butanol, and others)	Alcohol based inks can be used where the printer must operate at temperatures below the freezing point of water. An example of this is in-camera consumer photographic printing.	♦ Fast drying ♦ Operates at sub-freezing temperatures ♦ Reduced paper cockle ♦ Low cost	♦ Slight odor ♦ Flammable	♦ All IJ series ink jets

Phase change (hot melt)	The ink is solid at room temperature, and is melted in the print head before jetting. Hot melt inks are usually wax based, with a melting point around 80 °C. After jetting the ink freezes almost instantly upon contacting the print medium or a transfer roller.	♦ No drying time- ink instantly freezes on the print medium ♦ Almost any print medium can be used ♦ No paper cockle occurs ♦ No wicking occurs ♦ No bleed occurs ♦ No strikethrough occurs	♦ High viscosity ♦ Printed ink typically has a 'waxy' feel ♦ Printed pages may 'block' ♦ Ink temperature may be above the curie point of permanent magnets ♦ Ink heaters consume power ♦ Long warm-up time	♦ Tektronix hot melt piezoelectric ink jets ♦ 1989 Nowak USP 4,820,346 ♦ All IJ series ink jets
Oil	Oil based inks are extensively used in offset printing. They have advantages in improved characteristics on paper (especially no wicking or cockle). Oil soluble dies and pigments are required.	♦ High solubility medium for some dyes ♦ Does not cockle paper ♦ Does not wick through paper	♦ High viscosity: this is a significant limitation for use in inkjets, which usually require a low viscosity. Some short chain and multi-branched oils have a sufficiently low viscosity. ♦ Slow drying	♦ All IJ series ink jets
Microemulsion	A microemulsion is a stable, self forming emulsion of oil, water, and surfactant. The characteristic drop size is less than 100 nm, and is determined by the preferred curvature of the surfactant.	♦ Stops ink bleed ♦ High dye solubility ♦ Water, oil, and amphiphilic soluble dies can be used ♦ Can stabilize pigment suspensions	♦ Viscosity higher than water ♦ Cost is slightly higher than water based ink ♦ High surfactant concentration required (around 5%)	♦ All IJ series ink jets

Ink Jet Printing

A large number of new forms of ink jet printers have been developed to facilitate alternative ink jet technologies for the image processing and data distribution system. Various combinations of ink jet devices can be included in printer devices incorporated as part of the present invention. Australian Provisional Patent Applications relating to these ink jets which are specifically incorporated by cross reference include:

Australian Provisional Number	Filing Date	Title
PO8066	15-Jul-97	Image Creation Method and Apparatus (IJ01)
PO8072	15-Jul-97	Image Creation Method and Apparatus (IJ02)
PO8040	15-Jul-97	Image Creation Method and Apparatus (IJ03)
PO8071	15-Jul-97	Image Creation Method and Apparatus (IJ04)
PO8047	15-Jul-97	Image Creation Method and Apparatus (IJ05)
PO8035	15-Jul-97	Image Creation Method and Apparatus (IJ06)
PO8044	15-Jul-97	Image Creation Method and Apparatus (IJ07)
PO8063	15-Jul-97	Image Creation Method and Apparatus (IJ08)
PO8057	15-Jul-97	Image Creation Method and Apparatus (IJ09)
PO8056	15-Jul-97	Image Creation Method and Apparatus (IJ10)
PO8069	15-Jul-97	Image Creation Method and Apparatus (IJ11)
PO8049	15-Jul-97	Image Creation Method and Apparatus (IJ12)
PO8036	15-Jul-97	Image Creation Method and Apparatus (IJ13)
PO8048	15-Jul-97	Image Creation Method and Apparatus (IJ14)
PO8070	15-Jul-97	Image Creation Method and Apparatus (IJ15)
PO8067	15-Jul-97	Image Creation Method and Apparatus (IJ16)
PO8001	15-Jul-97	Image Creation Method and Apparatus (IJ17)
PO8038	15-Jul-97	Image Creation Method and Apparatus (IJ18)
PO8033	15-Jul-97	Image Creation Method and Apparatus (IJ19)
PO8002	15-Jul-97	Image Creation Method and Apparatus (IJ20)
PO8068	15-Jul-97	Image Creation Method and Apparatus (IJ21)
PO8062	15-Jul-97	Image Creation Method and Apparatus (IJ22)
PO8034	15-Jul-97	Image Creation Method and Apparatus (IJ23)
PO8039	15-Jul-97	Image Creation Method and Apparatus (IJ24)
PO8041	15-Jul-97	Image Creation Method and Apparatus (IJ25)
PO8004	15-Jul-97	Image Creation Method and Apparatus (IJ26)

PO8037	15-Jul-97	Image Creation Method and Apparatus (IJ27)
PO8043	15-Jul-97	Image Creation Method and Apparatus (IJ28)
PO8042	15-Jul-97	Image Creation Method and Apparatus (IJ29)
PO8064	15-Jul-97	Image Creation Method and Apparatus (IJ30)
PO9389	23-Sep-97	Image Creation Method and Apparatus (IJ31)
PO9391	23-Sep-97	Image Creation Method and Apparatus (IJ32)
PP0888	12-Dec-97	Image Creation Method and Apparatus (IJ33)
PP0891	12-Dec-97	Image Creation Method and Apparatus (IJ34)
PP0890	12-Dec-97	Image Creation Method and Apparatus (IJ35)
PP0873	12-Dec-97	Image Creation Method and Apparatus (IJ36)
PP0993	12-Dec-97	Image Creation Method and Apparatus (IJ37)
PP0890	12-Dec-97	Image Creation Method and Apparatus (IJ38)
PP1398	19-Jan-98	An Image Creation Method and Apparatus (IJ39)
PP2592	25-Mar-98	An Image Creation Method and Apparatus (IJ40)
PP2593	25-Mar-98	Image Creation Method and Apparatus (IJ41)
PP3991	9-Jun-98	Image Creation Method and Apparatus (IJ42)
PP3987	9-Jun-98	Image Creation Method and Apparatus (IJ43)
PP3985	9-Jun-98	Image Creation Method and Apparatus (IJ44)
PP3983	9-Jun-98	Image Creation Method and Apparatus (IJ45)

Ink Jet Manufacturing

Further, the present application may utilize advanced semiconductor fabrication techniques in the construction of large arrays of ink jet printers. Suitable manufacturing techniques are described in the following Australian provisional patent specifications incorporated here by cross-reference:

Australian Provisional Number	Filing Date	Title
PO7935	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM01)
PO7936	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM02)
PO7937	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM03)
PO8061	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM04)
PO8054	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM05)
PO8065	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM06)
PO8055	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM07)
PO8053	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM08)
PO8078	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM09)

PO7933	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM10)
PO7950	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM11)
PO7949	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM12)
PO8060	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM13)
PO8059	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM14)
PO8073	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM15)
PO8076	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM16)
PO8075	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM17)
PO8079	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM18)
PO8050	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM19)
PO8052	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM20)
PO7948	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM21)
PO7951	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM22)
PO8074	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM23)
PO7941	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM24)
PO8077	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM25)
PO8058	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM26)
PO8051	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM27)
PO8045	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM28)
PO7952	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM29)
PO8046	15-Jul-97	A Method of Manufacture of an Image Creation Apparatus (IJM30)
PO8503	11-Aug-97	A Method of Manufacture of an Image Creation Apparatus (IJM30a)
PO9390	23-Sep-97	A Method of Manufacture of an Image Creation Apparatus (IJM31)
PO9392	23-Sep-97	A Method of Manufacture of an Image Creation Apparatus (IJM32)
PP0889	12-Dec-97	A Method of Manufacture of an Image Creation Apparatus (IJM35)
PP0887	12-Dec-97	A Method of Manufacture of an Image Creation Apparatus (IJM36)
PP0882	12-Dec-97	A Method of Manufacture of an Image Creation Apparatus (IJM37)
PP0874	12-Dec-97	A Method of Manufacture of an Image Creation Apparatus (IJM38)
PP1396	19-Jan-98	A Method of Manufacture of an Image Creation Apparatus (IJM39)
PP2591	25-Mar-98	A Method of Manufacture of an Image Creation Apparatus (IJM41)
PP3989	9-Jun-98	A Method of Manufacture of an Image Creation Apparatus (IJM40)
PP3990	9-Jun-98	A Method of Manufacture of an Image Creation Apparatus (IJM42)
PP3986	9-Jun-98	A Method of Manufacture of an Image Creation Apparatus (IJM43)
PP3984	9-Jun-98	A Method of Manufacture of an Image Creation Apparatus (IJM44)
PP3982	9-Jun-98	A Method of Manufacture of an Image Creation Apparatus (IJM45)

Fluid Supply

Further, the present application may utilize an ink delivery system to the ink jet head. Delivery systems relating to the supply of ink to a series of ink jet nozzles are described in the following Australian provisional patent specifications, the disclosure of which are hereby incorporated by cross-reference:

Australian Provisional Number	Filing Date	Title
PO8003	15-Jul-97	Supply Method and Apparatus (F1)
PO8005	15-Jul-97	Supply Method and Apparatus (F2)
PO9404	23-Sep-97	A Device and Method (F3)

MEMS Technology

Further, the present application may utilize advanced semiconductor microelectromechanical techniques in the construction of large arrays of ink jet printers. Suitable microelectromechanical techniques are described in the following Australian provisional patent specifications incorporated here by cross-reference:

Australian Provisional Number	Filing Date	Title
PO7943	15-Jul-97	A device (MEMS01)
PO8006	15-Jul-97	A device (MEMS02)
PO8007	15-Jul-97	A device (MEMS03)
PO8008	15-Jul-97	A device (MEMS04)
PO8010	15-Jul-97	A device (MEMS05)
PO8011	15-Jul-97	A device (MEMS06)
PO7947	15-Jul-97	A device (MEMS07)
PO7945	15-Jul-97	A device (MEMS08)
PO7944	15-Jul-97	A device (MEMS09)
PO7946	15-Jul-97	A device (MEMS10)
PO9393	23-Sep-97	A Device and Method (MEMS11)
PP0875	12-Dec-97	A Device (MEMS12)
PP0894	12-Dec-97	A Device and Method (MEMS13)

IR Technologies

Further, the present application may include the utilization of a disposable camera system such as those described in the following Australian provisional patent specifications incorporated here by cross-reference:

Australian Provisional Number	Filing Date	Title
PP0895	12-Dec-97	An Image Creation Method and Apparatus (IR01)
PP0870	12-Dec-97	A Device and Method (IR02)
PP0869	12-Dec-97	A Device and Method (IR04)
PP0887	12-Dec-97	Image Creation Method and Apparatus (IR05)
PP0885	12-Dec-97	An Image Production System (IR06)
PP0884	12-Dec-97	Image Creation Method and Apparatus (IR10)
PP0886	12-Dec-97	Image Creation Method and Apparatus (IR12)
PP0871	12-Dec-97	A Device and Method (IR13)
PP0876	12-Dec-97	An Image Processing Method and Apparatus (IR14)
PP0877	12-Dec-97	A Device and Method (IR16)
PP0878	12-Dec-97	A Device and Method (IR17)
PP0879	12-Dec-97	A Device and Method (IR18)
PP0883	12-Dec-97	A Device and Method (IR19)
PP0880	12-Dec-97	A Device and Method (IR20)
PP0881	12-Dec-97	A Device and Method (IR21)

DotCard Technologies

Further, the present application may include the utilization of a data distribution system such as that described in the following Australian provisional patent specifications incorporated here by cross-reference:

Australian Provisional Number	Filing Date	Title
PP2370	16-Mar-98	Data Processing Method and Apparatus (Dot01)
PP2371	16-Mar-98	Data Processing Method and Apparatus (Dot02)

Artcam Technologies

Further, the present application may include the utilization of camera and data processing techniques such as an Artcam type device as described in the following Australian provisional patent specifications incorporated here by cross-reference:

Australian Provisional Number	Filing Date	Title
PO7991	15-Jul-97	Image Processing Method and Apparatus (ART01)
PO8505	11-Aug-97	Image Processing Method and Apparatus (ART01a)
PO7988	15-Jul-97	Image Processing Method and Apparatus (ART02)
PO7993	15-Jul-97	Image Processing Method and Apparatus (ART03)
PO8012	15-Jul-97	Image Processing Method and Apparatus (ART05)
PO8017	15-Jul-97	Image Processing Method and Apparatus (ART06)
PO8014	15-Jul-97	Media Device (ART07)
PO8025	15-Jul-97	Image Processing Method and Apparatus (ART08)
PO8032	15-Jul-97	Image Processing Method and Apparatus (ART09)
PO7999	15-Jul-97	Image Processing Method and Apparatus (ART10)
PO7998	15-Jul-97	Image Processing Method and Apparatus (ART11)
PO8031	15-Jul-97	Image Processing Method and Apparatus (ART12)
PO8030	15-Jul-97	Media Device (ART13)
PO8498	11-Aug-97	Image Processing Method and Apparatus (ART14)
PO7997	15-Jul-97	Media Device (ART15)
PO7979	15-Jul-97	Media Device (ART16)
PO8015	15-Jul-97	Media Device (ART17)
PO7978	15-Jul-97	Media Device (ART18)
PO7982	15-Jul-97	Data Processing Method and Apparatus (ART19)
PO7989	15-Jul-97	Data Processing Method and Apparatus (ART20)
PO8019	15-Jul-97	Media Processing Method and Apparatus (ART21)
PO7980	15-Jul-97	Image Processing Method and Apparatus (ART22)
PO7942	15-Jul-97	Image Processing Method and Apparatus (ART23)
PO8018	15-Jul-97	Image Processing Method and Apparatus (ART24)
PO7938	15-Jul-97	Image Processing Method and Apparatus (ART25)
PO8016	15-Jul-97	Image Processing Method and Apparatus (ART26)
PO8024	15-Jul-97	Image Processing Method and Apparatus (ART27)
PO7940	15-Jul-97	Data Processing Method and Apparatus (ART28)
PO7939	15-Jul-97	Data Processing Method and Apparatus (ART29)
PO8501	11-Aug-97	Image Processing Method and Apparatus (ART30)

PO8500	11-Aug-97	Image Processing Method and Apparatus (ART31)
PO7987	15-Jul-97	Data Processing Method and Apparatus (ART32)
PO8022	15-Jul-97	Image Processing Method and Apparatus (ART33)
PO8497	11-Aug-97	Image Processing Method and Apparatus (ART30)
PO8029	15-Jul-97	Sensor Creation Method and Apparatus (ART36)
PO7985	15-Jul-97	Data Processing Method and Apparatus (ART37)
PO8020	15-Jul-97	Data Processing Method and Apparatus (ART38)
PO8023	15-Jul-97	Data Processing Method and Apparatus (ART39)
PO9395	23-Sep-97	Data Processing Method and Apparatus (ART4)
PO8021	15-Jul-97	Data Processing Method and Apparatus (ART40)
PO8504	11-Aug-97	Image Processing Method and Apparatus (ART42)
PO8000	15-Jul-97	Data Processing Method and Apparatus (ART43)
PO7977	15-Jul-97	Data Processing Method and Apparatus (ART44)
PO7934	15-Jul-97	Data Processing Method and Apparatus (ART45)
PO7990	15-Jul-97	Data Processing Method and Apparatus (ART46)
PO8499	11-Aug-97	Image Processing Method and Apparatus (ART47)
PO8502	11-Aug-97	Image Processing Method and Apparatus (ART48)
PO7981	15-Jul-97	Data Processing Method and Apparatus (ART50)
PO7986	15-Jul-97	Data Processing Method and Apparatus (ART51)
PO7983	15-Jul-97	Data Processing Method and Apparatus (ART52)
PO8026	15-Jul-97	Image Processing Method and Apparatus (ART53)
PO8027	15-Jul-97	Image Processing Method and Apparatus (ART54)
PO8028	15-Jul-97	Image Processing Method and Apparatus (ART56)
PO9394	23-Sep-97	Image Processing Method and Apparatus (ART57)
PO9396	23-Sep-97	Data Processing Method and Apparatus (ART58)
PO9397	23-Sep-97	Data Processing Method and Apparatus (ART59)
PO9398	23-Sep-97	Data Processing Method and Apparatus (ART60)
PO9399	23-Sep-97	Data Processing Method and Apparatus (ART61)
PO9400	23-Sep-97	Data Processing Method and Apparatus (ART62)
PO9401	23-Sep-97	Data Processing Method and Apparatus (ART63)
PO9402	23-Sep-97	Data Processing Method and Apparatus (ART64)
PO9403	23-Sep-97	Data Processing Method and Apparatus (ART65)
PO9405	23-Sep-97	Data Processing Method and Apparatus (ART66)
PP0959	16-Dec-97	A Data Processing Method and Apparatus (ART68)
PP1397	19-Jan-98	A Media Device (ART69)